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GLACIAL AND MARINE CHRONOLOGY OF MARS;

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A hydrological model involving episodic oceans and ice sheets on Mars has been presented by Baker, *et al.* (1,2). One of the main uncertainties concerning this model is the age and correlation of these events. Even more uncertain are their absolute ages. However, based on stratigraphic and cratering evidence, the most recent occurrence of these events was relatively late in Martian history.

The cratering record on Mars can be divided into three general periods: 1) the period of late heavy bombardment, 2) a transition period at the end of late heavy bombardment, and 3) the post heavy bombardment era (3). The crater size/frequency distribution represented by the period of late heavy bombardment is characterized by a complex curve with a differential -2 slope (cumulative -1) at diameters less than about 50 km diameter, while the post heavy bombardment size distribution has a differential -3 slope (cumulative -2) over the same diameter range (Fig. 1). On the Martian time-stratigraphic scale, the period of late heavy bombardment occurred during Noachian and Early Hesperian time and came to an end during the Middle Hesperian. The post heavy bombardment era began in Late Hesperian time and extends through the Amazonian Epoch to the present day (3).

Although a Noachian ocean is suggested as a theoretical consequence of a warm, wet early Mars (4,5), as an element in the hydrological cycling responsible for the widespread Noachian valley networks, and a cause of an erosional episode near the end of late heavy bombardment (6), there is no direct evidence for such an ocean. Evidence for a more recent sporadic formation of great northern plains oceans has been presented by Parker, *et al.* (7). Since most of the northern plains are Late Hesperian (3,8) these oceans cannot be older. The outflow channels, thought to be the sources of the oceans, show multiple flow episodes and ages ranging from Late Hesperian to Late Amazonian (8). High density valleys on Alba Patera have been attributed to water runoff possibly associated with a nearby ocean (9). The age of the surface on which these superposed valleys occur is Early Amazonian indicating the valleys and ocean are younger (Early to Middle Amazonian). Chapman, *et al.* (10) present evidence that the Elysium basin was occupied by an ephemeral sea which they date as Amazonian based on stratigraphic evidence. This "sea" may have been part of the late ocean mentioned above.

There is mounting evidence that widespread episodic glaciation occurred in the southern hemisphere southward of about -40 degrees (2, 11, 12, 13). The most detailed studies are of the Argye and Hellas regions (11, 12, 13). Crater counts in the Hellas basin, presented in a companion abstract by Johnson *et al.* (13), indicate that the Hellas glaciation occurred during the Middle Amazonian. We also counted craters on the southern floor of Argyre occupied by ridges (eskers). Although there is evidence for at least two glacial epochs, the esker plains appear to be the most recent. The craters were divided into three types: 1) craters with ejecta blankets, 2) craters with no visible ejecta blankets but relatively sharp rims, and 3) no ejecta blankets and highly degraded rims. The craters with ejecta blankets are probably post glaciation and equivalent to ejecta blanket craters in Hellas. Fig. 2 is an "R" plot of the size/frequency distribution of eject blanket craters on the Argyre esker plains and similar craters in Hellas. Also shown for reference are the Northern Plains (Late Hesperian) and the Tharsis Volcanic Plains (Amazonian). The Hellas and Argyre curves are essentially identical within the errors, indicating similar ages of glaciation during Middle Amazonian time. The glacial features (eskers, outwash plains, etc.) recognized in Argyre, Hellas and elsewhere (11. 12, 13) require glacial melting and running water for relatively long periods of time. This in turn requires a temperate climate with summer temperatures above the melting point of ice during Middle Amazonian time. Fig. 3 summarizes the relative chronology of oceans, ice sheets and other major events in Martian history.

The absolute ages of these events is very uncertain and depends on one's assumptions about the origin of the impacting objects and the cratering rate. If the period of late heavy bombardment ended the same time on Mars and the Moon, then the Middle Hesperian is about 3.8 Gy old. However, if the objects responsible for late heavy bombardment were accretional remnants, their sweep-up time at Mars would be extended by about 1 Gy due to perturbations of the objects into the u_6 secular resonance (14). In this case the Middle Hesperian is about 2.8 Gy old. Thus, ocean and ice sheet formation on Mars must be substantially younger than 3.8 or 2.8 Gy. Depending on different models (15, 16), the Middle Amazonian could be anywhere between about 2.3 to 0.25 Gy, and therefore ice sheets and a temperate climate were present sometime during this time span. In a separate abstract (12) we estimate that the Middle Hesperian glacial epoch lasted for a period on the order of 2 million years, to an order of magnitude.

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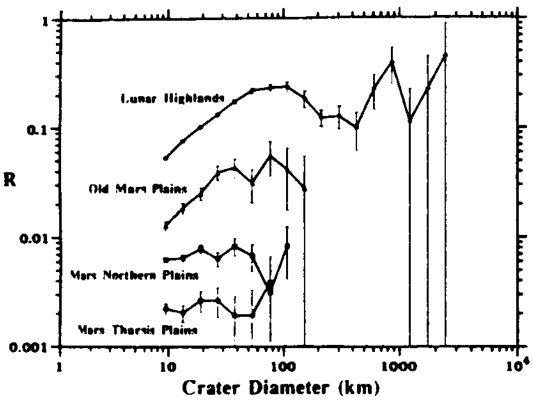

Fig. 1. "R" plot of the crater size/frequency distribution of the lunar highlands, martian old plains (Early Hesperian), Mars Northern Plains (Late Hesperian), and Mars Tharsis Plains (Amazonian).

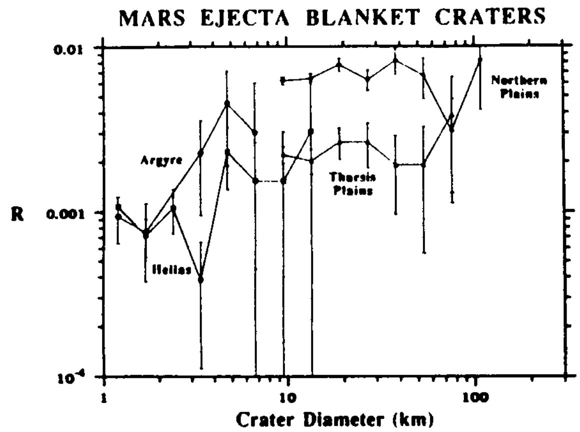

Fig. 2. "R" plot of the size/frequency distributions of post-glacial craters in Argyre and Hellas compared to the martian Northern and Tharsis Plains.

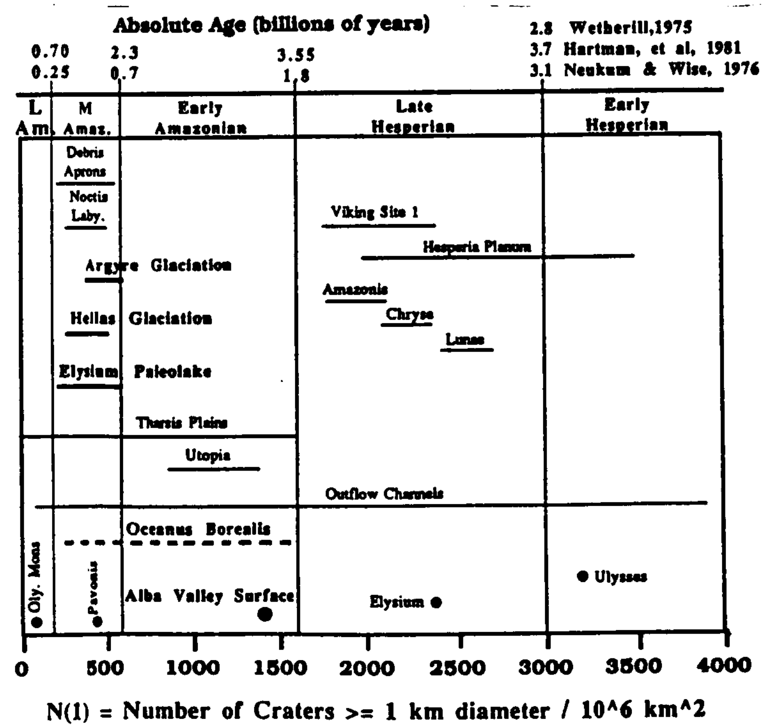

Fig. 3. Summary of the time-stratigraphic age of ice sheet and ocean formation together with several other major events in Martian history.